MAINTENANCE COST STUDY OF ROTARY
WING AIRCRAFT

INTERIM PHASE II

August 1979

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I. Introduction

The vertical takeoff and landing (VTOL) aircraft market has had substantial growth in both the military and civil sector in the past decade. Especially apparent is the rapid expansion of helicopter use in natural resource exploration, law enforcement and civil utility applications. These applications have indicated the need for more advanced rotary wing technology and have pointed the way to other applications. An important factor in the utility of advanced VTOL aircraft is their expected maintenance costs. Recent military experience has indicated that helicopter maintenance manhours per flight hour may be double those of fixed-wing aircraft of the same payload capacity. Helicopters in civil transport use have been reported to have high maintenance costs; however, this conclusion is drawn from very limited data and besides the aircraft are older and in limited use. In view of the importance of maintenance requirements to the economic viability and operational suitability of VTOL aircraft, the ability to predict and evaluate future maintenance needs is necessary. Of prime interest is the impact which new technologies may have on these maintenance costs. This includes the ability to assess the potential economic gains in reduced maintenance needs through introduction of advances in any of the propulsion system components and flight controls mechanisms.

The primary objective of this rotary wing aircraft maintenance study was to determine which systems required the major maintenance

attention and the feasibility of predicting maintenance costs based on major system characteristics and aircraft time in flight. This would be the first step in understanding the relationships between maintenance costs and design factors. Then, if relationships could be identified and quantified for existing aircraft, these would become a sound foundation for building estimating techniques with relation to future advanced technology vehicles. Time and budget would not make prudent the analysis of the entire cost spectrum involved in rotary wing maintenance; however, as the study developed, it became apparent that feasible maintenance characteristics could be established by careful examination of unscheduled maintenance. Unscheduled maintenance is that maintenance which is performed to correct malfunctions resulting from normal operational wear or damage.

The Maintenance Cost Study of Rotary Wing Aircraft to date has been conducted in two phases. Within Phase I, the methodology was developed that identified the impact to Direct Maintenance Man Hours per Flight Hour (DMMH/FH) in terms of key design factors such as number of engines, transmission gear ratio, average flight duration, etc. The experience as recorded in the U.S. Navy's Maintenance and Material Management data base was used as its basis. The validity of the resultant equations that evolved from this effort, was from eleven different military rotary wing aircraft. The salient results from Phase I are included in this report as they are necessary background for the understanding of the results of this Phase II effort.

The Phase I results identified the major operational and design variables which effect the maintenance requirements for military helicopter dynamic systems; therefore the need was to determine what variables were the important factors when helicopters are used in civil applications. These uses included off-shore oil exploration and support, police and fire department rescue and enforcement, logging and heavy equipment movement as well as U.S. Army military operations. Very limited funding was available to pursue such a broad area. Thus the effort reported herein was planned as an interim, exploratory effort. The decision was made to maximize this effort by concentrating on the civil users with the bigger fleets; thus five non-military users were contacted. These users employ from five to over two-hundred thirty helicopters in their fleets.

From this limited sample, reported herein is a description of the approach, the sources, the nature and uncertainties of the data, the method of analysis employed, and a discussion of the quantitative and qualitative results obtained.

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II. **Phase I**

The basic objective of this Phase was to investigate the feasibility
of predicting unscheduled maintenance costs for the dynamic systems of
military rotary wing aircraft based upon design and utilization factors.
A study of this nature requires an extensive data base. Of the extensive
military data available, the U.S. Navy's Maintenance and Material Management
(3-M) data base was selected because of the high number of variables recorded,
ease of access and relative freedom of bias of the data. The 3-M system
contains data about all maintenance actions at both organizational and
intermediate levels of maintenance for all Naval aircraft. To form the
data base for this study, two years, 1974 and 1975 of data were extracted
for the following Naval and Marine Corps rotary wing aircraft:

UHIE	SH3A	CH46D
	SH3D	CH46F
UHIN	SH3G	CH53A
SH2F	SH3H	CH53D

The data base, in its final form, contained a total of 260,202 maintenance
actions, 1,150,186 maintenance man hours, 209,224 flight and 351,580 flight
hours.

The 3-M data base contains maintenance reporting from both the USMC
and USN which provides a wide sample of aircraft type. In terms of depth,
the number of aircraft in the fleet and the flying hours accumulated, the

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sample size was sufficiently large for each aircraft type. Data is reported at a detailed level so that information can be extracted at the major subsystem, major assembly, or subassembly level. The 3-M data is quite homogeneous in that all maintenance is performed in accordance with the same policy dictated by fleet-wide directives. The skill level and training of mechanics and technicians is also as uniform as it is possible to obtain. The four dynamic component subsystems selected for evaluation were the rotor, transmission, engine and flight controls. In addition, all of the dynamic subsystems were grouped and were examined as a single dynamic system. Multiple variable regression techniques were used to examine each of the dependent and independent variables.

The candidate design and operational factors that were considered by the step-wise multiple regression are as follows:

Number of Engines

Number of Main Rotors

Number of Tail Rotors

Number of Main Rotor Blades

Number of Tail Rotor Blades

Average Flight Duration

Flights Per Aircraft Per Month

Total Engine Horsepower

Aircraft Weight

Transmission Gear Ratio

Main Rotor Diameter

Disk Loading

Horsepower/Weight Ratio

Various combinations of these terms were selected as independent
variables in the step-wise multiple regression analysis to determine the
Direct Maintenance Man Hours per Flight Hour (DMMH/FH). Only those terms
providing the best correlation to DMMH/FH were selected. The result was
an equation for each system that provided accurate predictors of DMMH/FH.

Figure I provides the maintenance equation for the engine system.
As may be seen, of the thirteen candidate design factors, only five were
found by the regression program to be significant from an engineering,
mechanical and logic consideration as well as from a DMMH/FH predictor
viewpoint. These five variables, as well as the determined constant
multiplier for each are shown on the figure.

Three statistical tests were used to evaluate the resultant equation,
and these results are shown in Figure I. First, the correlation coefficient
was examined. The correlation coefficient, when adjusted for the number of
variables, gives the percentage of variance in the dependent variable which
is explained by the independent variables in the equation. The closer the
correlation coefficient is to I, the better the equation is statistically.
The second test examined the F ratio. The "F" ratio considers the amount

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MAINTENANCE EQUATION

(MILITARY AIRCRAFT)

ENGINE SYSTEM

$$DMMH/FH = .48668N - .69131F - .20819M - .14598H - .03940W + 5.17397$$

Where: N = Number of Engines

F = Average Flight Duration, Hours

M = Number of Flights Per Aircraft Per Month

H = Total Horsepower in Megawatts

W = Maximum Weight in Megagrams

CORRELATION COEFFICIENT = .934

	Model	95% Critical Value
F-Value	12.14	5.05
T-Value N	3.80	2.02
F	5.77	2.02
M	4.20	2.02
H	1.99	2.02
W	1.26	2.02

Figure I

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of variance explained by the independent variables. From a table of the "F" distribution, 5 percent value of F was used for comparison with the specific F ratio for the equation. This test hypothesis is that there is no actual correlation between the dependent variable and the independent variables, and the apparent relationship is only due to chance. If the specific F ratio is greater than the 5 percent value of F, then the test hypothesis can be rejected with 95 percent confidence. The third test, was to determine the T ratios for each individual coefficient. This ratio is designed to determine if each coefficient makes a statistically significant contribution to the entire equation. These ratios are computed by dividing each independent variable's coefficient by its corresponding standard error. From a table of the "T" distribution, the 5 percent value of T was used for comparison with the specific T ratio under test.

As may be noted on figure I, the 95% critical F value was 5.05; the result obtained was 12.14 which is highly acceptable. Figure I also shows the results of examining the T values. As can be seen, the number of engines (N), the average flight duration (F), and the flights per aircraft per month (M) greatly exceeded the 95% critical value. This is reflected in the relatively large constant that is multiplied with each of the selected design characteristics. The total horsepower in megawatts (H) was less than 1% below the 95% critical value; however, the maximum weight in megagrams was 38% below the 95% critical value and this is reflected by the very small multiplier. Naturally, the smaller the multiplier, the less important that design characteristic is as a DMMH/FH predictor.

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Figures 2, 3 and 4 respectively identify those design characteristics that can be used as a predictor of DMMH/FH for the flight controls, rotor and transmission systems.

By summing the equations for all four systems the equation to achieve DMMH/FH for the entire dynamic system can be developed. However, regression analysis was exercised to achieve one maintenance equation for the total dynamic system. This resulting equation is shown in figure 5. It is somewhat surprising by its simplicity for the maximum weight (W) and the main rotor diameter (D) are quite significant as DMMH/FH predictors and the flights per aircraft per month are somewhat less significant. Lacking from this equation are the variables of number of engines, number of rotor blades, total horsepower, etc., that were found to be significant as predictors for the individual dynamic systems.

After the equations were developed, the predicted DMMH/FH for the individual systems were totaled for each of the eleven aircraft types, and the DMMH/FH was predicted for each aircraft's total dynamics system. These two total values were then compared to the actual DMMH/FH and the results of this comparison are shown in figure 6.

The conclusion reached at the completion of Phase I was that the results obtained clearly indicate the feasibility of predicting DMMH/FH for US Navy rotary wing aircraft from design and operating data. Unanswered was the question about how well these same relationships would hold up for non-military helicopter users. The purpose of Phase II of the study was to investigate this question.

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MAINTENANCE EQUATION

(MILITARY AIRCRAFT)

FLIGHT CONTROL SYSTEM

$$DMMH/FH = .02124H - .46127F - .14422M - .05581B + 3.88951$$

Where: H = Total Horsepower in Megawatts

F = Average Flight Duration, Hours

M = Flights Per Aircraft Per Month

B = Total Number of Rotor Blades

CORRELATION COEFFICIENT = .955

	Model	95% Critical Value
F-Value	22.636	4.53
T-Value (H)	0.337	1.94
(F)	2.737	1.94
(M)	3.448	1.94
(B)	1.185	1.94

Figure 2

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MAINTENANCE EQUATION

(MILITARY AIRCRAFT)

ROTOR SYSTEM

$$DMMH/FH = .1439W - .07933D + 1.01333$$

Where: W = Maximum Weight in Megagrams

D = Main Rotor Diameter in Meters

CORRELATION COEFFICIENT = .966

	Model	95% Critical Value
F-Value	61.76	4.66
T-Value (W)	8.11	1.86
(D)	2.93	1.86

Figure 3

MAINTENANCE EQUATION

(MILITARY AIRCRAFT)

TRANSMISSION SYSTEM

$$DMMH/FH = .0021W + .07559G - .39997F - .03247M + 1.26165$$

Where: W = Maximum Weight in Megagrams

G = Transmission Gear Ratio

F = Average Flight Duration, Hours

M = Flights Per Aircraft Per Month

CORRELATION COEFFICIENT = .923

	Model	95% Critical Value
F-Value	13.06	4.53
T-Value (W)	.103	1.94
(G)	3.93	1.94
(F)	3.26	1.94
(M)	.827	1.94

Figure 4

MAINTENANCE EQUATION

(MILITARY AIRCRAFT)

DYNAMIC SYSTEM

$DMMH/FH = .34026W - .35290D - .15414M + 8.24741$

Where: W = Maximum Weight in Megagrams

D = Main Rotor Diameter in Meters

M = Flights Per Aircraft Per Month

CORRELATION COEFFICIENT = .951

	Model	95% Critical Value
F-Value	28.299	4.35
T-Value (W)	6.096	1.89
(D)	3.029	1.89
(M)	8.997	1.89

Figure 5

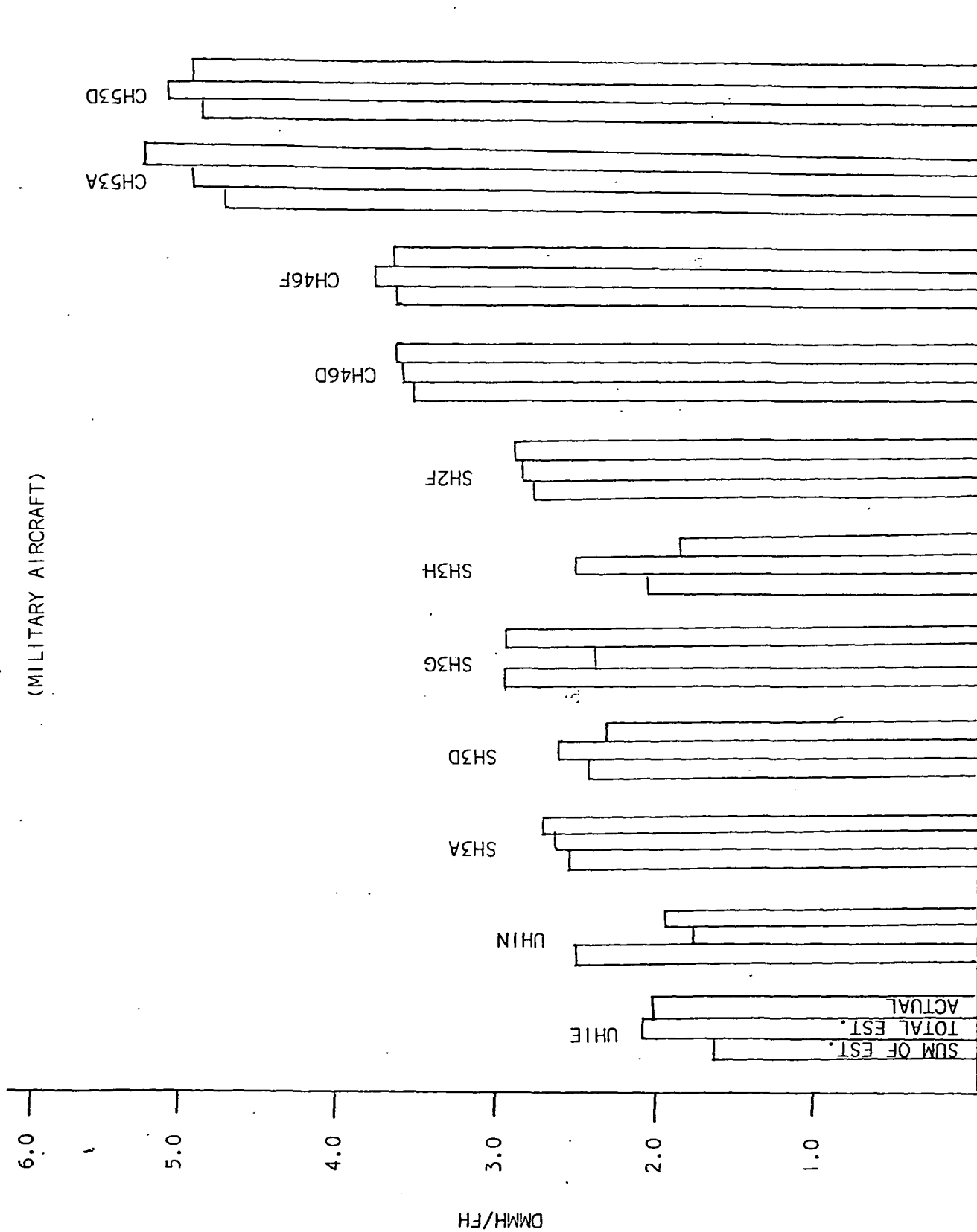HELICOPTER DYNAMIC SYSTEM UNSCHEDULED MAINTENANCE ACTIONS

(MILITARY AIRCRAFT)

Figure 6

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III. Phase II

The purpose of the Phase II effort was to examine the reliability and maintenance (R&M) experiences of commercial operators to determine if their R&M experiences were similiar to those of the U.S. Navy. There are numerous non-military operators of helicopters. They perform tasks that go all the way from transport, through police, ambulance, firefighting, oil exploration, oil-rig support, logging and bulky machinery moving. It was the intention in this phase to examine a representative number of these operations using a good cross-section of currently available helicopters in order to gather a meaningful data base. However, a limited amount of funding was available by NASA. This required that this Phase be limited. This Phase thus became an interim study and was limited to investigating the R&M experiences of oil-rig support and police operators. It was hoped that these maintained the best R&M records of their operations and helicopters.

The following non-military users were contacted to obtain data about their rotary wing operations:

- Petroleum Helicopters, Mr. Robert L.Suggs, President
- Los Angeles Police Department, Capt. Richard Ungerecht
- Baltimore City Police Department, Capt. Ray R. Raffensberger
- Maryland State Police Department, Capt. Robert Moore
- Los Angeles County Sheriff's Dpet., Capt. Peter Montgomery
- Huntington Beach Police Department, Lt. Robert M. Morrison

The personnel identified above operate over 290 aircraft and there are ten different models represented within this total. Prior to the personal visit, each individual was sent a copy of the Phase I final report. Without exception, each individual contacted freely discussed their operations and went to great lengths to provide any information they had at their disposal. The interview took two directions, one dealt with qualitative comments and the other with quantitative R&M information. Both of these areas are important, as one cannot fully appreciate the civil operator's R&M experience by reviewing only quantitative information.

Operation Experience

The qualitative comments will be discussed first as they give basis to understanding the R&M costs. At the outset, it should be mentioned that non-military users are not entirely satisfied with their rotary wing aircraft. The following are four of the most often made comments.

1. For the most part, the helicopters available to non-military users are those that evolved from military designs with military missions in mind.

2. With the design fixed for military missions, the non-military user's helicopters are outfitted for bankers who purchase one helicopter and fly it 20 hours a month instead of for that segment who buy many helicopters (even hundreds) and fly them hundreds of hours a month. As an example, door handles, floor boards, corrosion protection, access doors, etc., are

at best minimally acceptable. At the worst, they must all be replaced -- often times before they fly the first flight.

3. U.S. helicopter technology has lost way to European technology. When the European companies improve the logistic support of their spare parts, they will become increasingly more competitive.

4. Each user has several different mission requirements. For example, a few of the missions of those users contacted are: ambulance, surveillance, traffic monitoring, crew changes, cargo delivery, rescue operations, fire department activities, etc. Each of these represent unique range and payload requirements. The users feel they do not have enough of a selection for an opportunity to select different helicopters that satisfy particular missions.

A major difference between military and non-military users of helicopters is uniformity of operations. One military squadron, with an occasional exception, operates and maintains their helicopters similarly to any other squadron within the same service. The non-military users, however, have few similarities in their operations. The maintenance of their helicopter provides an excellent example. .The maintenance concept employed by the users visited ranged from total commercial (outside) maintenance; to limited organizational maintenance; to full organizational and limited intermediate; to total organizational, intermediate and depot maintenance capability. The operational characteristics are also different even between police departments - one patrols a reasonably small area, another patrols an

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enormous area. One user flies regularly scheduled missions; another will use the majority of its resources for emergency and rescue operations only.

Maintenance Analysis

One thing the non-military users do have in common is the lack of a detailed data collection system for maintenance. Those police departments with organic capability are very short handed, and they have traded off detailed maintenance records for wrench turning. The Police Departments that use commercial maintenance authorize maintenance tasks; they are told how many labor hours are expended per aircraft but there is no easily obtained detailed record of what part was repaired.

There was one exception to the nonavailability of data. For a one year period, the maintenance personnel of this Police Department recorded the maintenance actions against each helicopter at both the main maintenance facility and also at the flying center. During a period of nine months 3377 maintenance man hours were expended upon the Department's 206 B's. During that same period of time the aircraft flew 14,820 hours which computes to .23 direct maintenance man hours/flight hours. The maintenance actions would conform almost exclusively to the Navy's Remove and Replace actions at the organizational level. As would be expected this value is considerable below the organizational remove and replace time for the Navy's helicopter experience partly because of a more rigorous Navy data collection system and partly because of the considerably more complex equipment in Navy helicopters.

Another important element in the R&M data collected from each of the non-military users is their sense of prioprietary rights. It is obvious that a commercial operator does not make his actual maintenance costs readily available, for these information are one facet of his competitive edge. These data are more often given in generalized terms with enough qualitative information supplied to be able to develop trends. The police departments are each different, with some being relatively open while others are very protective of their operational data. Even where the data are available, a department would prefer that their R&M data not be labeled. This means that for the data given herein for non-military users, these data were aggregated and averages or trends are available for print but no specific numbers or sources have been so identified.

The R&M cost relations developed from the military aircraft data base was used as a basis for an analysis of a non-military operation. The most commonly used commercial helicopter is the Bell Model 206-B. It was used as an example. This aircraft has the following design and average operational characteristics:

Number of Engines	1.0
Horsepower in Megawatts	.313
Max Weight in Megagrams	1.451
Total Rotor Blades	4.0
Main Rotor Diameter in Meters	10.16
Transmission Gear Ratio	15:21
Average Flight Duration	2 Hours
Flights Per Aircraft Per Month	40

The flight duration and flights per month vary widely within organizations and between organizations. One of the organizations visited, reported flying 150 hours per month per aircraft. Others fly considerably less, but some at times fly amazingly even more. Accordingly, it was found that an average for these commercial and public services helicopter operators was about 40 flights per aircraft per month. The average flight duration of two hours was representative even though some flight durations are considerably less and others are almost twice as long. In these two items, is a good example of prime differences between the military and non-military users. On the other hand, military users have consistent flying of $1\frac{1}{2}$ to $2\frac{1}{2}$ hours and only fly 15 times a month. These gross differences should be caution for guarded conclusions when military R&M relations are applied to commercial or public service users.

The design and flight characteristics described earlier for the Bell 206 B were incorporated into the maintenance equation for the engine system (see figure 1). The result is as follows:

$$DMMH/FH = .48668(1) - .69131(2) - .20819(40) - .14598(.313)$$
$$- .03940(1.451) + 5.17397$$

$$DMMH/FH = - 4.152$$

A negative value for DMMH/FH, of course, is an unacceptable value but the reason for it can be seen when the equation is examined. The two design characteristics with the greatest opportunity of driving the answer to be negative are mission duration and flights per aircraft per month.

Whereas the equation was developed with mission durations of 1.5 to 2.5 hours and an average aircraft flights of between 10 and 15 flights per month. These two factors are more than doubled by the non-military users. The impact on the maintenance man hours for the engine system by decreasing only the number of flights per month and holding all other values constant is shown in figure 7.

The cost equation for the flight control system was also examined (figure 2). It contains flight duration and the flights per aircraft per month as variables. As might be expected, this equation behaves in a similar manner.

$$DMMH/FH = .02124(.313) - .46127(2) - .14422(40)$$
$$- .05581(4) + 3.88951$$

$$DMMH/FH = - 3.018$$

Just as with the engine system, the result is negative because of the effect of the large number of flights per month.

The rotor system equation (figure 3) does not contain either flight duration or flights per month.

$$DMMH/FH = .1439(1.451) - .07933(10.61) + 1.01333$$

$$DMMH/FH = .416$$

COMPARISON OF ENGINE SYSTEM MAINTENANCE

BY USE OF MILITARY EXPERIENCE

Key

⊙ Non-Military
✗ Military

DMMH/FH
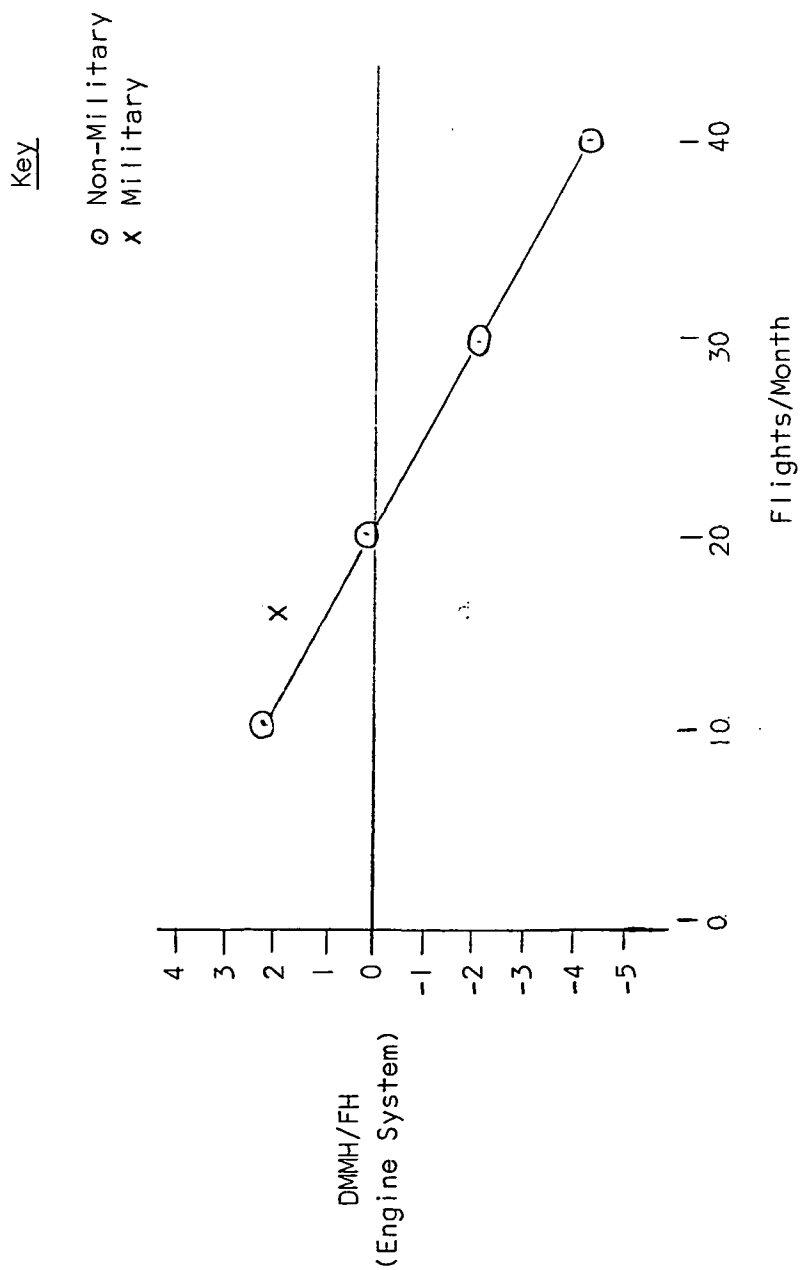(Engine System)

Flights/Month

Figure 7

The DMMH/FH for rotors of military aircraft ranges from .41 to 2.10

so the prediction appears to be reasonable. Unfortunately it was not

possible to obtain actual maintenance times expended by the non-military

users on their rotor systems so no actual value for comparison is possible.

The transmission system equation (figure 4) uses the flights per month

and the flight duration but their impact is less significant because of

the size of their coefficient. The predicted DMMH/FH seems reasonsable.

$$DMMH/FH = .0021(1.451) + .07559(15) - .3997(2) - .03427(40)$$
$$+ 1.26165$$

$$DMMH/FH = .228$$

The maintenance equation for the entire dynamic system (figure 5)

again has a large coefficient for the flights per aircraft per month

and the result is not acceptable.

$$DMMH/FH = .34026(1.451) - .35290(10.16) - .15414(40)$$
$$+ 8.24741$$

$$DMMH/FH = - 1.010$$

As explained earlier, the maintenance equations of Phase I were obtained

using only the military data base. Because of the obvious poor results in

several of the systems when used for non-military operators, it was decided

to redevelop by regression analysis a new equation for the total dynamic

system using data from both military and non-military operators. The results of this analysis are shown below. The military base only equation is given for comparison.

Military Data Base Only

DMMH/FH (Total Dynamic System) = .34026 Gross Weight (mg)

    - .35290 Rotor Diameter (m) - .15414 Flights/AC/Month

    + 8.24741   (See Figure 5)

Combined Military and Non-Military Data Base

DMMH/FH (Total Dynamic System) = .35561 Gross Weight (mg)

    - .26925 Rotor Diameter (m) - .04429 Flights/AC/Month

    + 4.93894

Using the combined data equation, the DMMH/FH estimate for the Bell 206-B changes from a negative value to a value of 0.948.

No data were available to verify directly the prediction; but with one bit of information and a few assumptions a fair indirect verification can be made. That is, the number of maintenance personnel at one of the large non-military operators and the total number of hours flown per year were obtained. From these it was possible to determine the total direct maintenance man hour per flight hour of 4.2 for all levels of maintenance. Now if some assumptions are made, for example, depot operations consume 10% of the total man hours expended for maintenance, the 4.2 would reduce to a DMMH/FH of 3.78. In

normal operations, 70% of all maintenance actions are unscheduled which would give a DMMH/FH (UNSCH) of 2.65. Some references have indicated that on rotary wing aircraft without sophisticated avionic packages that the dynamic subsystems account for anywhere from 44 to 56% of all maintenance actions. Accordingly a prediction near 1.16 to 1.40 for DMMH/FH (UNSCH DYNAMIC SUBSYSTEMS) would be indicated for this operator when these assumptions are used. That value is reasonably close to the 0.95 value from the above equation.

Obviously, the number of non-military operators contacted and the amount of R&M information acquired is too small to develop any firm conclusions, but it is obvious from the discussion that the military and non-military operations are decidedly different. One important difference is the missions and mission profile. More important is the availability of the actual R&M data. The military service R&M experience is readily available, whereas the commercial operator is competitive and his R&M data are proprietary and often can only be acquired in general terms. However, with only a limited non-military data base some general R&M trends can be developed.

IV. Study Limitations

The objective of the rotary wing aircraft maintenance cost study was to determine the feasibility of predicting maintenance costs based on top level design variables and utilization factors. It was decided that feasibility could be established by careful examination of a few of the more major contributors to the overall costs. For rotary wing aircraft the total maintenance costs can be expressed as:

Total Cost = Unscheduled Cost + Inspection Costs + Support Cost

Unscheduled maintenance is that maintenance which is performed to correct defects resulting from normal operational wear or damage. It includes the cost for the repair of defects detected during scheduled inspections as well as the bench repair of removed components. Inspections include all maintenance actions which are prior planned by the operator. They occur either for a certain calendar period or time as for accrued operating hours. Support is all the usual routine servicing actions involved in aircraft operation. These include such items as fuel servicing, washing, cleaning and ground handling. The support costs are most dependent on a particular operator's procedures and may be only slightly impacted by design factors.

The unscheduled maintenance costs were examined for this study because they are unpredictable and account for the larger percentage of maintenance labor hours than inspections. This can be seen in the

comparisons of the total non-support labor hours presented in Table I. This table is for two randomly selected one month U.S. Navy operations of the SH3D aircraft, and it shows that unscheduled labor accounts for approximately 70% of all non-support type man hours.

The effort was also limited by selection of those cost items that are related to overall aircraft design. The aircraft dynamic subsystems appeared to meet these criteria. In Table 2 are tabulated the total maintenance man hours expended for unscheduled maintenance for the four dynamic subsystems over a two year period for eleven different rotary wing aircraft. The dynamic subsystems account for from 27% to 56% of the total man hours expended. It should be noted that the SH2F and SH3 series aircraft have an antisubmarine warfare mission and are thus equipped with more extensive and sophisticated avionics which require considerable maintenance. The dynamic subsystems in these types in actual hours expended, are comparable to the other 6 helicopters.

TABLE I

SH3 TOTAL LABOR HOUR BREAKDOWN

	MONTH I		MONTH 2	
	HRS	%	HRS	%
UNSCHEDULED LABOR	5348	71	2143	69
INSPECTION LABOR	2148	29	986	31
TOTAL	7496	100	3129	100

TABLE 2

DYNAMIC COMPONENT AND TOTAL AIRCRAFT

MAINTENANCE MAN HOUR COMPARISON

AIRCRAFT TYPE	TOTAL UNSCHEDULED MMH	DYNAMIC SUBSYSTEMS	
		UNSCHEDULED MMH	% OF TOTAL
UHIE	160305	70790	44
UHIN	142332	79948	56
CH46D	483125	216551	45
CH46F	483232	234868	49
CH53D	409106	190266	47
CH53A	218182	100282	46
SH2F	281973	99977	35*
SH3A	221576	68810	31*
SH3D	349298	100203	29*
SH3G	388622	119059	31*
SH3H	123559	32860	27*

* Aircraft include sophisticated avionics requiring
  high maintenance.

NOTE: Above data are derived from Navy 3M records covering
calendar years 1974 and 1975 for all USN and USMC
using activities.

It thus appeared from this preliminary analysis and the work to date confirms this opinion that by investigating the unscheduled maintenance costs for the dynamic subsystems, that they would give representative results. Within these boundaries, the study was limited to investigate the relationships between major aircraft design factors and maintenance labor requirements.

Since multiple regression analysis is the analytic tool usually employed in this type of study, successful application of this technique requires a data base with a sufficient number of observations to provide statistical validity. The first phase of the study addressed this requirement. Also necessary is the parallel collection of aircraft design information to select the independent variables. The selected variables were then subjected to regression analysis to test their applicability and predictive capability. This sampling gave an indication of the number of different helicopter types, models, operations and extent of maintenance and design data developed in Phase I.

In this interim study, the start of the Phase II effort, the data available was more subjective or qualitative than quantitative. It was thus necessary to conjecture some of the data to see if it was applicable. A trend resulted, but a greater number of non-military operators must be sampled before any confident maintenance relations can be developed.

Summary and Recommendations

The regression equations developed during Phase I of this study were found to be highly effective in predicting unscheduled direct maintenance man hours per flying hours for the dynamic subsystem of military rotary wing aircraft.

These equations were found to be less effective when used to predict unscheduled DMMH/FH for commercial or public service helicopters primarily because of the longer mission durations and the much higher utilization of these civil users. However, when these user's data are included with the military data base, from which the regression equations are formed, the resultant maintenance relations appear to be reasonable. Further validation of these equations for commercial and public service users was not possible because of the limitations in the scope of the study. Further work is very necessary in pursuing the basic objective of Phase II of this study. It has been found that developing limited results such as these in this interim work often unearths and makes available other information sources. This Phase II effort should be continued even on a limited basis so as to find at some future time the various helicopter components and assemblies which make helicopter maintenance so costly.

The work started in Phase I and continued in this initial effort of Phase II should be continued by further studies in the following three specific ways:

1. There are many civil users of helicopters who have not been contacted regarding their helicopter usage or maintenance and repair experience. These data need to be collected and combined with those data already collected and analyzed to reflect the various civil missions and maintenance trends.

2. The U.S. Army missions with helicopters and the maintenance requirements resulting from these missions should be collected, analyzed and compared with the U.S. Navy experience. Those mission variables which cause the higher dynamic system failures should be delineated.

3. Within the helicopter dynamic systems, those subsystems critical to maintenance costs need to be identified. Also to be identified are the design practices and technology requirements that could potentially reduce these critical maintenance costs. Those areas where the NASA should and/or could concentrate research in order to reduce maintenance costs and improve helicopter readiness should be outlined and ordered by priority. This work could be done concurrently with items 1 and 2 above.

The comments of the non-military users are important enough to be repeated again.

1. Most heliocpters available to non-military users are those that evolved from military designs with military missions in mind, and they were not designed for any particular non-military mission.

2. The non-military helicopters mostly are marketed and outfitted
    for executive users who purchase only one helicopter infrequently
    and fly it 20 hours a month instead of for that segment who buy
    many helicopters each year and fly each over a hundred hours a
    month.

3. The European helicopter companies are designing helicopters for
    the non-military user market, and when they improve their spare
    parts support, they will become more competitive in the U.S.
    market.

4. Each non-military user has several different range, payload and
    mission requirements. The users feel they do not have enough
    of a selection for an opportunity to select nor to buy different
    helicopters each for separate specific missions.